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FEASIBILITY REPORT ON MULTIPACTOR SWITCHES.(U)

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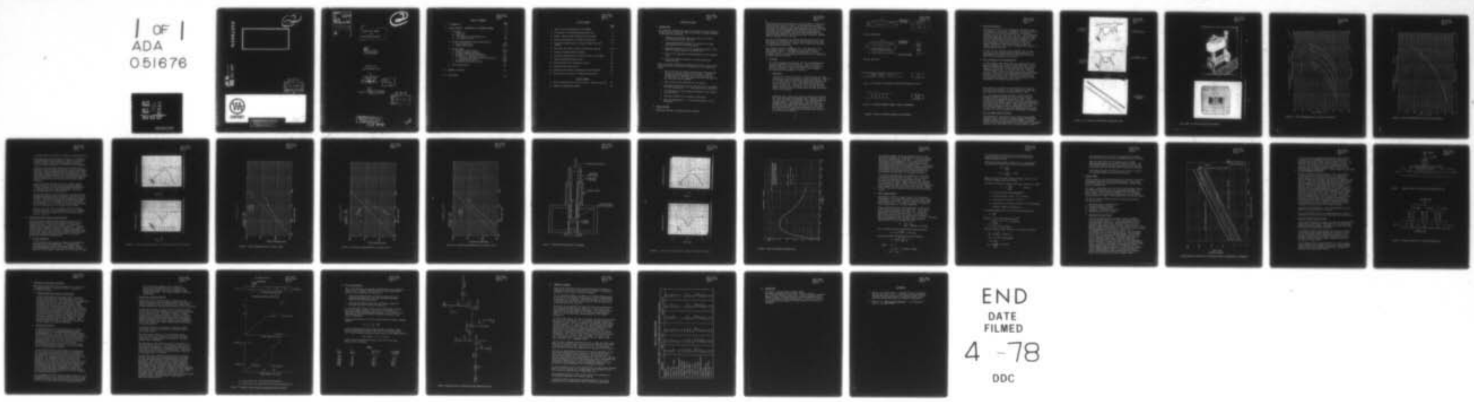

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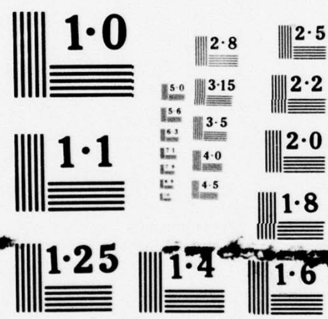

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FEASIBILITY REPORT ON MULTIPACTOR SWITCHES

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VAR-R-45002

Prepared For
NAVAL RESEARCH LABS

By
VARIAN ASSOCIATES
BEVERLY, MA

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FEASIBILITY STUDY

I. INTRODUCTION

This study was undertaken as part of a multipactor switch program conducted under contract No. N00173-76-C-0294. The major interests of the study are as follows:

1. Operation with design input levels from 1 kw to 50 kw while maintaining high isolation.
2. Average power handling capability relative to incident peak power with 10 to 50% duty cycle.
3. Bandwidth extension up to full waveguide bandwidth (I and J bands) including effects on insertion loss.
4. Unit to unit reproducibility with emphasis on the transmit state.
5. Driver requirements relative to switching speed and repetition rate.

There are several fundamental boundaries which exist within a multipactor switch which will serve as guidelines for this feasibility report.

1. The circuit must be capable of passing the full peak power through all portions of the circuit length. Primarily voltage gradients determined by dc switch biasing and RF levels must be consistant with pulse width, gap spacing, and localized circuit impedance.
2. Space charge limited operation will be assumed.
3. Secondary emission ratio greater than unity will be limited to striking potentials in the range of 25 to 2500 volts.
4. The capacitance of the multipactor devices will be limited to 50 to 100 pf.
5. Switching voltage will be limited to 2500 volts.
6. Only the fundamental $N = 1$, $\lambda/2$ mode multipactor will be considered.

II. DESIGN FACTORS

Background obtained on hardware phase of program.

The major effort on the program has been to develop a J band multipactor switch centered at 15 GHz. The desired device presents challenges with regard to high impedance circuitry, high secondary emission at low striking potentials, bandwidth, insertion loss, and very small spacing. Mundane challenges with stepped brazing techniques were presented by the use of Beryllium and Beryllium Copper secondary emitters and with processing to maintain secondary emission for good life of the unit.

Not all of the challenges were met satisfactorily within the time and funding restrictions, and in fact there are most likely some challenges yet unrecognized. However, much progress has been made in understanding the devices.

The original work for a multipactor switch was sponsored in the early 1960's by Rome Air Development Center under contract AF30(602)1641, Ref. 1. The work was performed by a Division of General Electric Company which was purchased with its technology by Varian Associates in 1965.

A. Circuitry

As in most microwave tube designs, the circuit determines the overall characteristics of the device. When the circuit is understood and well suited to the application, the degree of success is optimized. Much of the effort on this program was concerned with evaluation of circuits.

1. Ridge Line

The initial circuit explored was a ridge line with one ridge isolated so it could be biased to inhibit multipactor. (Fig. 1A) The isolated ridge was called the "modulating electrode" and it was supported by a rather complicated choke system and heliaced in position. The net results were high insertion losses and difficulty in matching. Full solution for this support system could not be found within the time and funding limits of the program.

Nontheless such a device was built and tested with extremely fast switching capability measured with a sampling scope as less than 5 nanosec, and indirectly with a spectrum analyzer as approximately 1 1/2 nanoseconds. The relatively low impedance of the distrubuted transmission line resulted in multipactoring at power level of 30 to 35 kw. This level was much too high for the hardware phase but the results fit nicely into the feasibility study where power levels of up to 50 kw are of interest.

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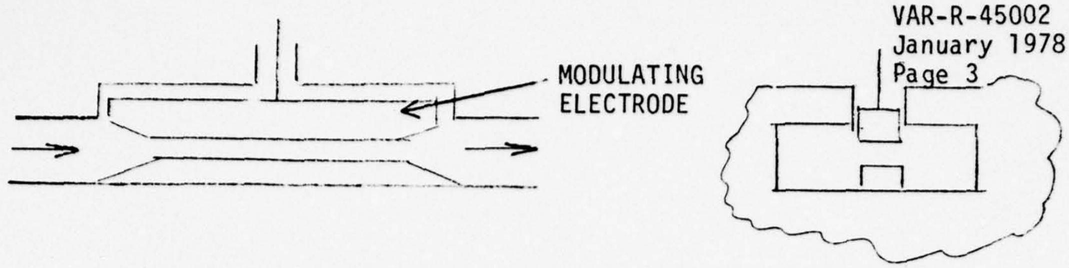


FIG 1A. RIDGE LINE

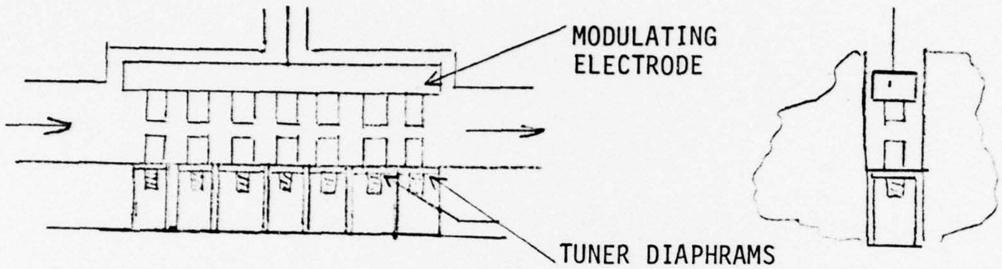


FIG 1B. COMB LINE

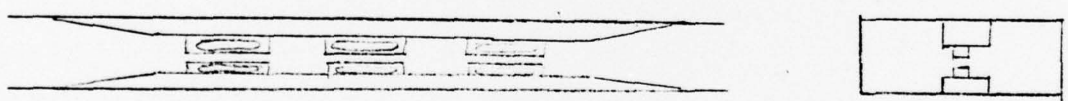


FIG 1C. $\lambda/4$ COUPLED $\lambda/2$ RESONATOR DISTRIBUTED TRANSMISSION LINE

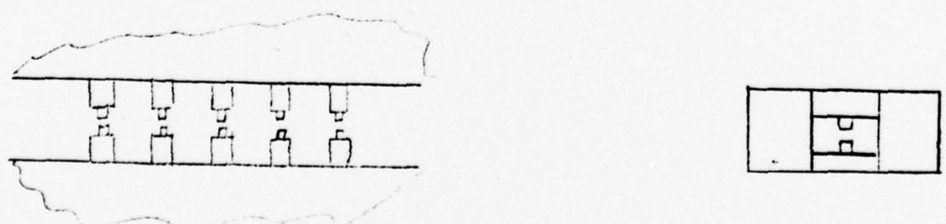


FIG 1D. $\lambda/4$ COUPLED RESONANT WINDOW (BLUNT TR ELEMENTS)

FIGURE 1. TYPES OF CIRCUITS EXPLORED ON THE PROGRAM

2. Comb Line Structure

The desired circuit for this program was initially a comb line because it offers high impedance. The early work with the comb line circuit was complicated by the mounting structure as was the ridge line, but the more fundamental difficulty experienced was how to tune the individual combs for optimum match and proper multipactor resonance at each section. The solution to tuning was an adaption of TR tube technology as indicated in Figure 1B. Here thin copper diaphrams are stretched to change the gaps for tuning. During this study, the bias feature was retained in the modulating electrode.

Circuits of this type were never assembled into a vacuum structure on this program because of the conversion to a more elementary circuit, the $\lambda/4$ coupled blunt TR circuit which will be described in section A-4.

3. The $\lambda/4$ Coupled, $\lambda/2$ Distributed Line

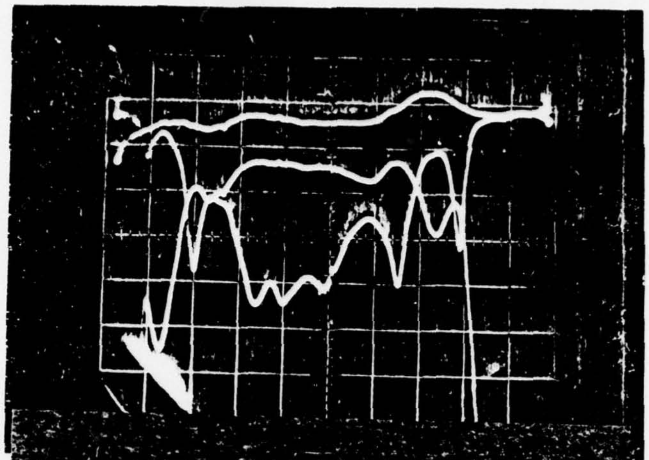
In time sequence, the circuit work next concentrated on the basic distributed line, similar to the ridge line. In an effort to resonate the line and thereby build up effective impedance, $\lambda/2$ sections of the ridge line were coupled by $\lambda/4$ high impedance line, as shown in Figure 1C. This was the first line tested on the program which demonstrated simultaneously a good match, broad bandwidth and insertion loss of approximately one (1) dB. Match and transmission data are therefore reproduced as Figure 2A while Figure 2C is a photograph of the actual waveguide inserts.

Close spacing is essential for multipactoring at low peak RF levels and therefore it is most significant to note that these data were recorded with gap spacings of .005".

In a crude attempt to show that such a circuit could be biased to provide switching, one half of the circuit was isolated from the waveguide by the use of tape. Total capacitance was measured as 200 pf which would be impractical to switch at high speeds; however, one or two sections of 30 pf each became realistic to switch. Most important is the fact that the gap between the line was reduced to .003" with relativly minor changes in low level characteristics as shown in Figure 2B. This is essential if low leakage is important.

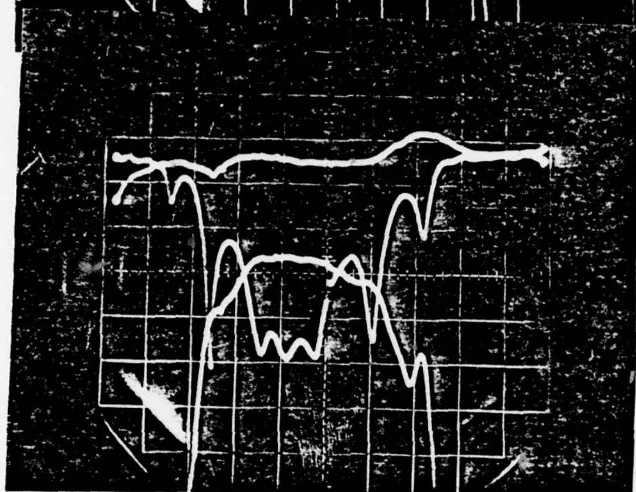
4. The $\lambda/4$ Coupled Blunt TR Circuit

The elementary TR tube consists of a series of $\lambda/4$ coupled resonant windows. Basically a resonant window differs from resonant transmission line in that the window is a lumped element whereas the transmission line is distributed. In essence then the circuit described in A-3 is quite similar to that in



Li=1dB/cm
RL=5dB/cm

A.
LIMITER CIRCUIT

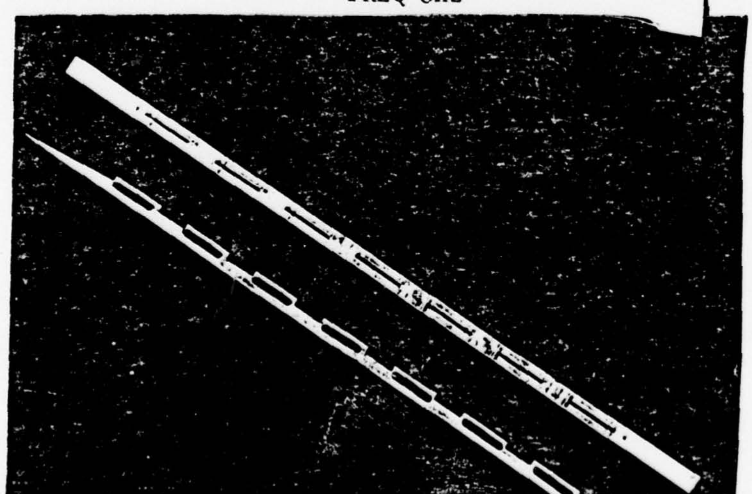


Li=1dB/cm
RL=5dB/cm

B.
SWITCHABLE CIRCUIT

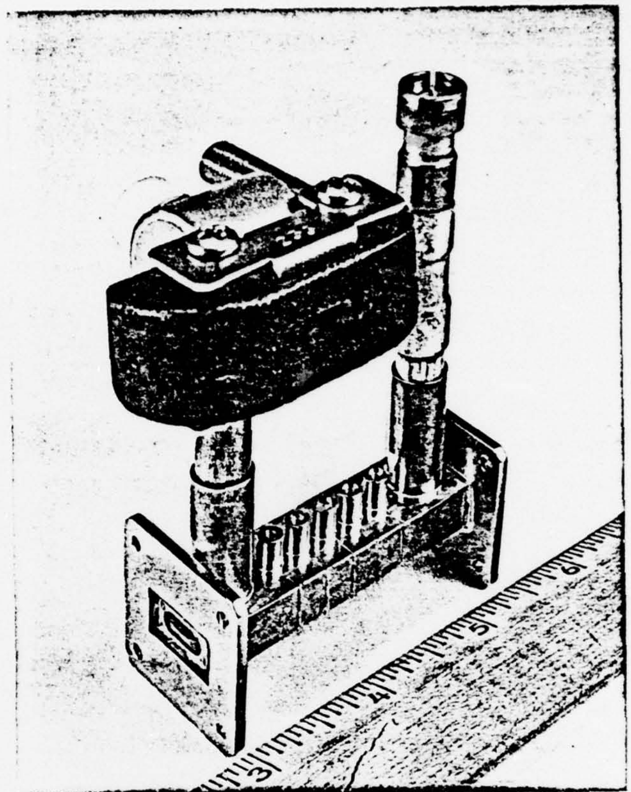
12.5 14.5 16.5

FREQ GHz

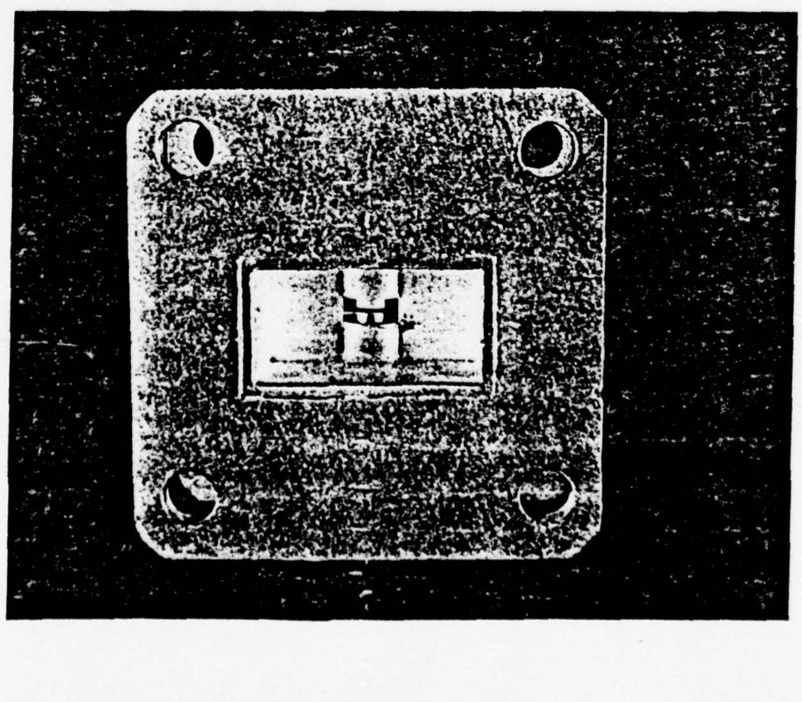


C.
PHOTOGRAPH of
INSERTS

FIGURE 2. $\lambda/4$ COUPLED $\lambda/2$ DISTRIBUTED TRANSMISSION LINE



3B.



3A

FIG 3. BLUNT TR TYPE MULTIPACTOR TEST CIRCUITS

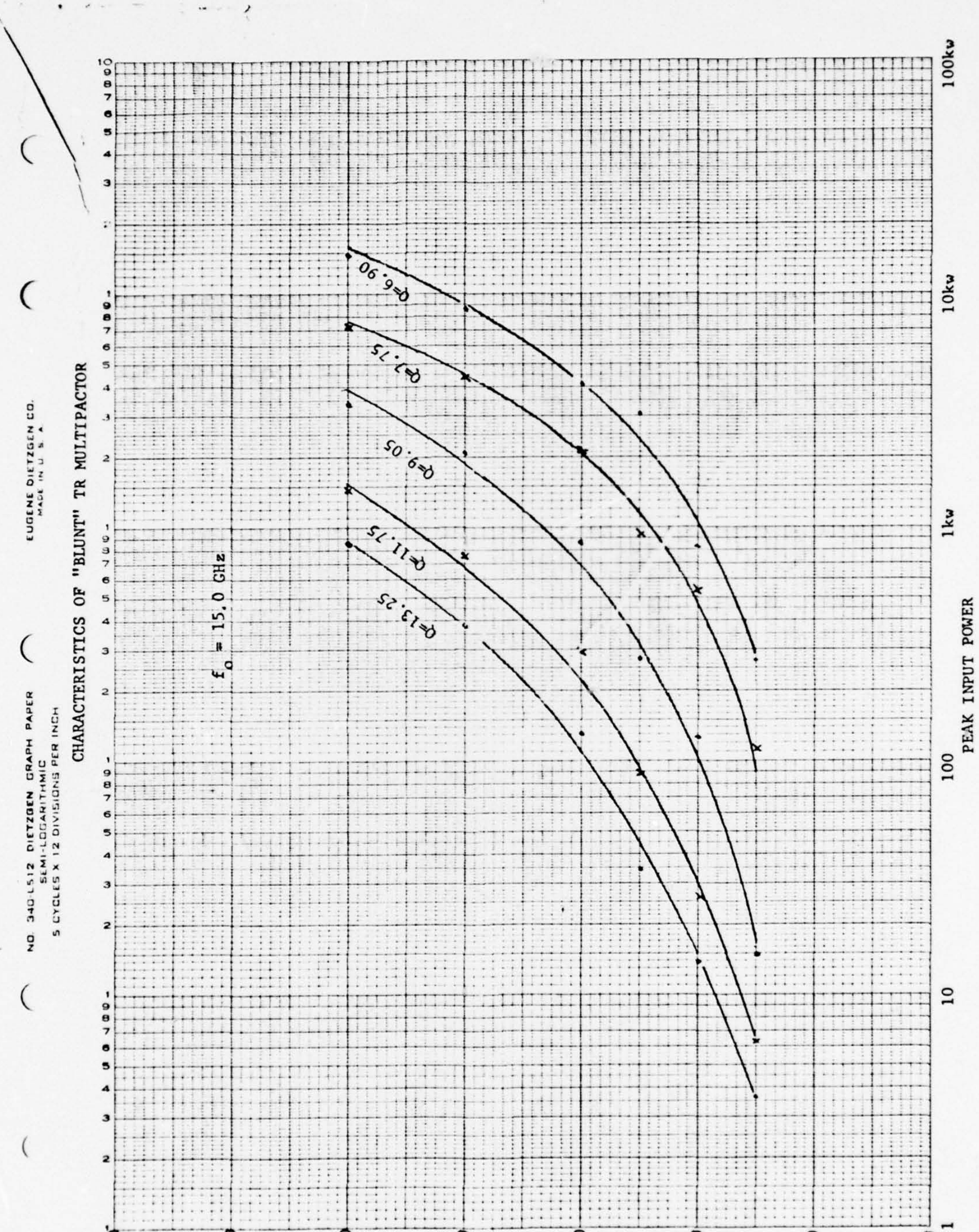


FIGURE 4A. DESIGN CHARACTERISTICS OF BLUNT TR MULTIPACTOR

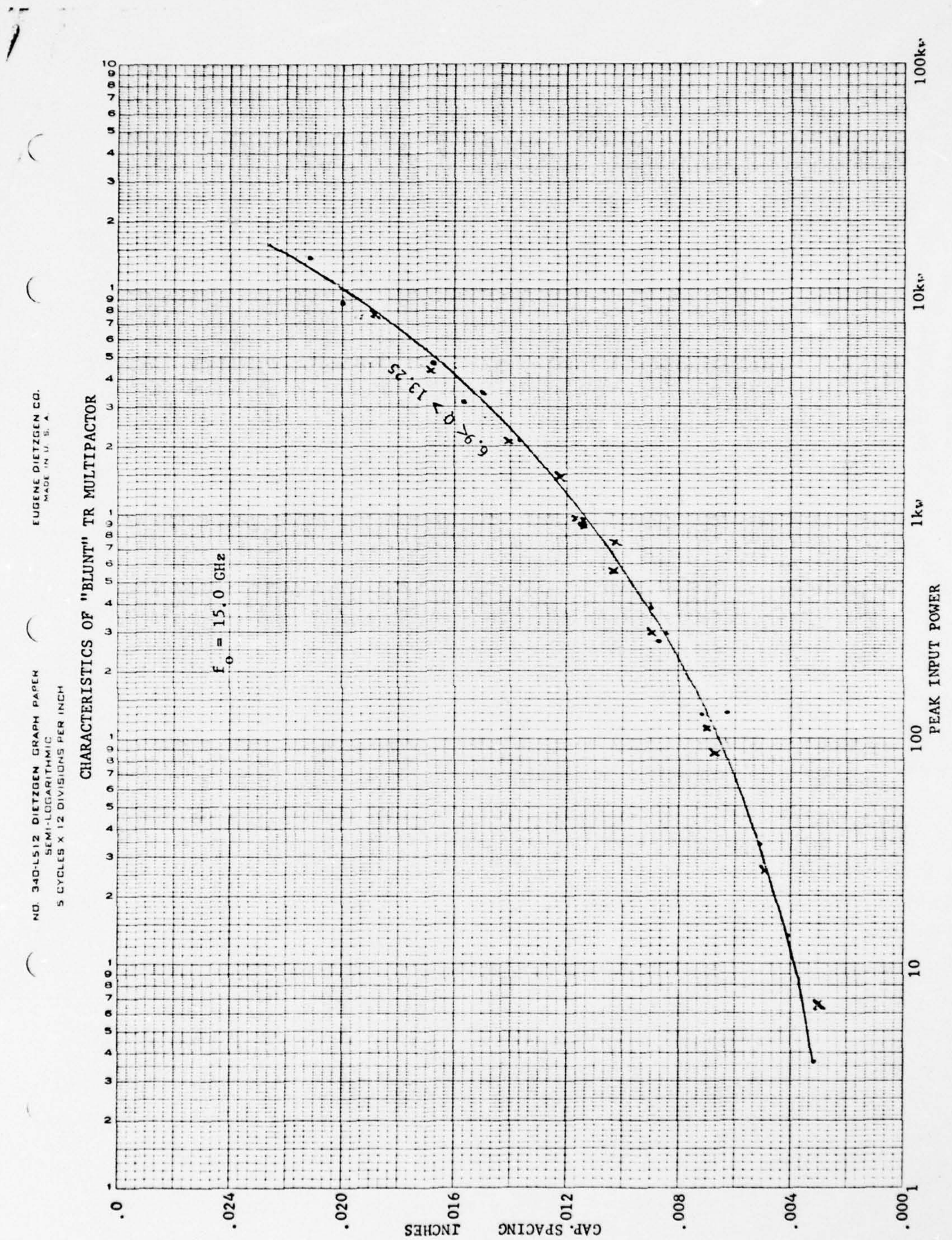


FIGURE 4B. DESIGN CHARACTERISTICS OF BLUNT TR MULTIPACTOR

a TR tube except it consists of lengths of distributed line.

By blunting the TR tip as shown in Figure 1D, a relatively large multipactor area was provided. When the potential of this TR type circuit for the multipactor switch was realized, Varian concentrated its efforts on this approach.

A series of single element testers were evaluated, which described the Q, the blunt gap spacing, and the gap diameter. From this, resonant impedance were calculated which in turn were used to calculate the multipactor resonant power level. The complete design information for the frequency, peak power level, and bandwidth of interest is summarized in Figure 4. Similar design curves could be made for any other band or frequency.

Typical low level characteristics for a single element blunt multipactor resonator without switching capability is shown in Figure 5. High level multipactor performance is indicated in Figure 6 where transmitted, reflected, and absorbed powers are characterized.

The gap spacing and low level resonance data indicated the multipactor resonant power of 1400 watts. Actual test data indicates multipactor limiting from approximately 200 watts to 3 kw. The low level corresponds to higher order modes while the 3 kw limit corresponds to the "Fire Through" of the fundamental, $N = 1$, $\lambda/2$ mode where synchronous condition cannot be maintained even with space charge loading.

Figure 7 is a sketch of a switchable section of resonant blunt TR type gap. Figure 8 represents low level response of a test section for comparison with the limiter type of section. (Fig. 5)

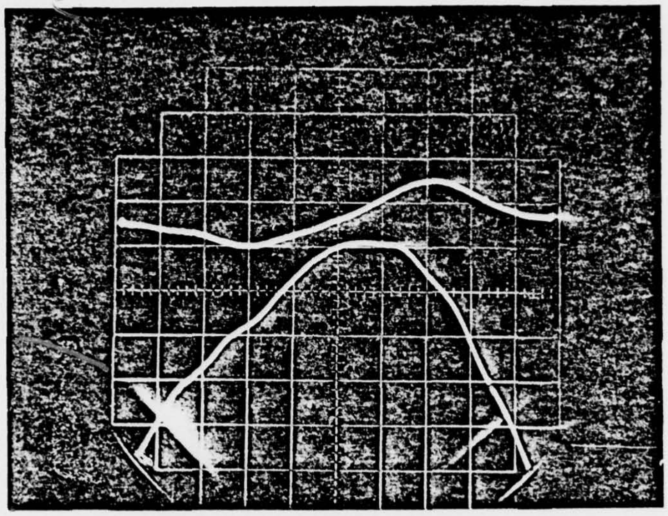
B. Surface Conditions and Space Charge Effects

From a practical standpoint space charge will build up in a multipactor device only when the secondary emission yield is greater than unity. This yield of course is a function of election striking potentials and surface condition. A typical characteristic is shown in Figure 9. Because of the need for low threashold levels associated with a feed through power level of less than 5 watts peak, the effort concentrated on Beryllium oxide surface which has been used successfully in Varian's SFD-261 CFA (Crossed Field Amplifier).

1. Surface Conditions

In the CFA, the surface oxide is removed by backbombarding electrons and by ion bombardment. To replenish this thin oxide surface a heated cupric oxide oxygen source is operated throughout the life of the CFA and the internal pressure of this oxygen is monitored via a small Vac Ion pump.

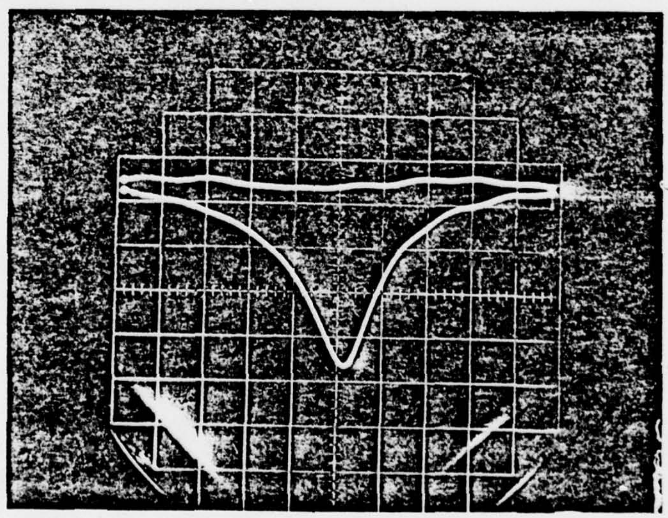
INSERTION LOSS 1dB/cm



14 15 16

FREQ GHz

RETURN LOSS 5dB/cm



14 15 16

FREQ GHz

FIGURE 5. Low Level Characteristics of Single Element "Hot Test" Limiter

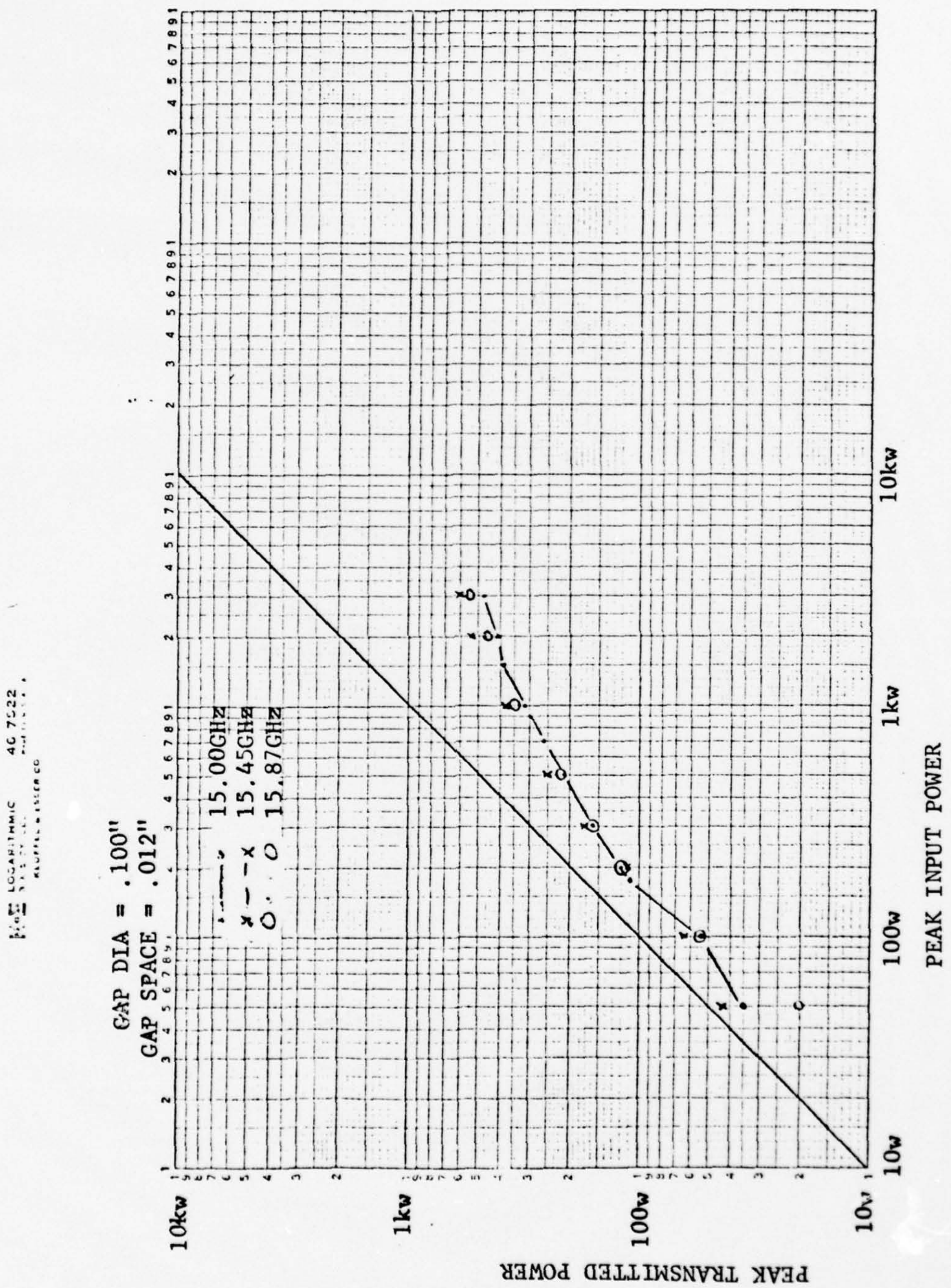


FIGURE 6A. OUTPUT CHARACTERISTICS OF SINGLE TESTER

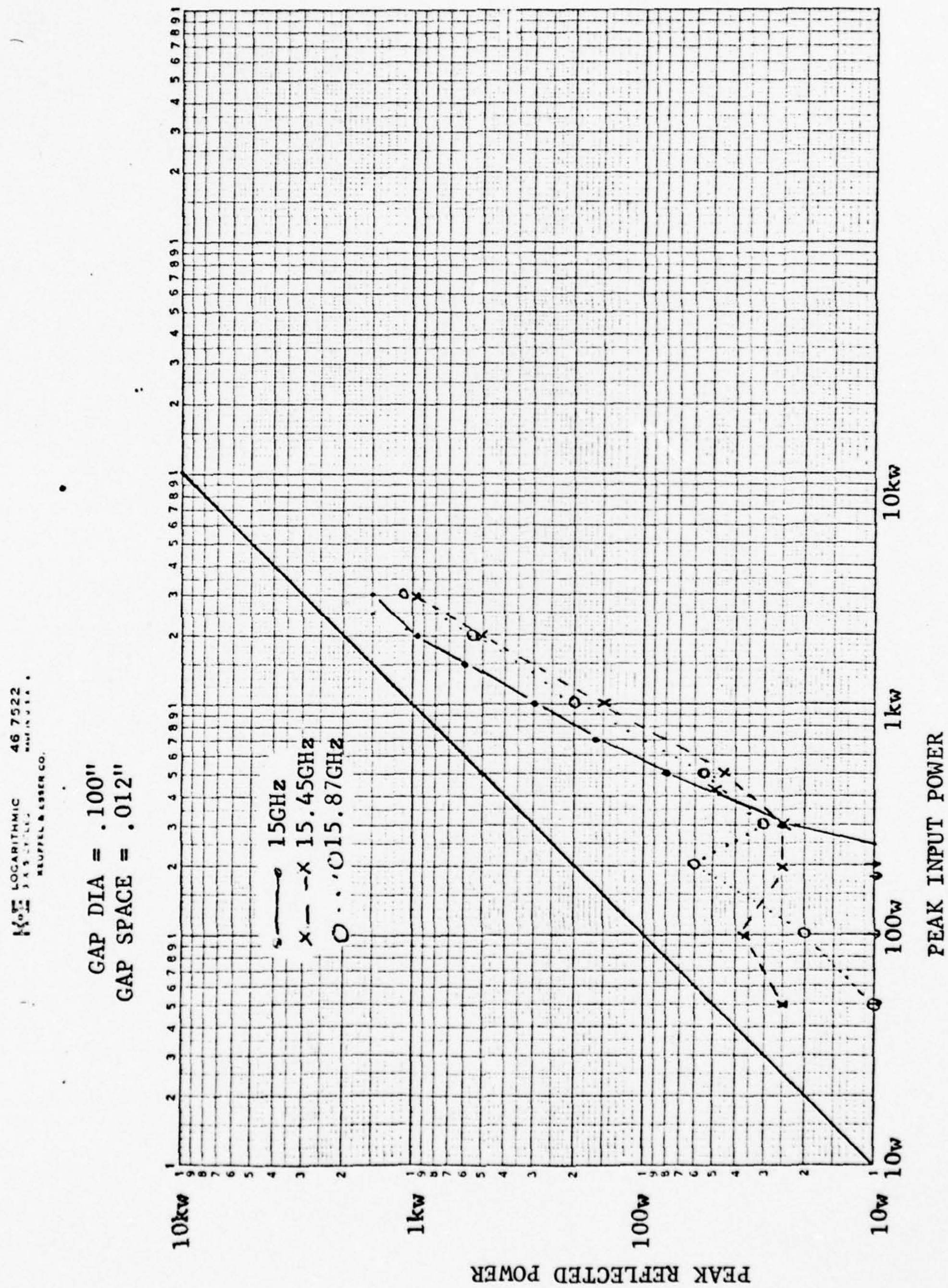


FIGURE 6B. REFLECTION CHARACTERISTICS OF SINGLE TESTER

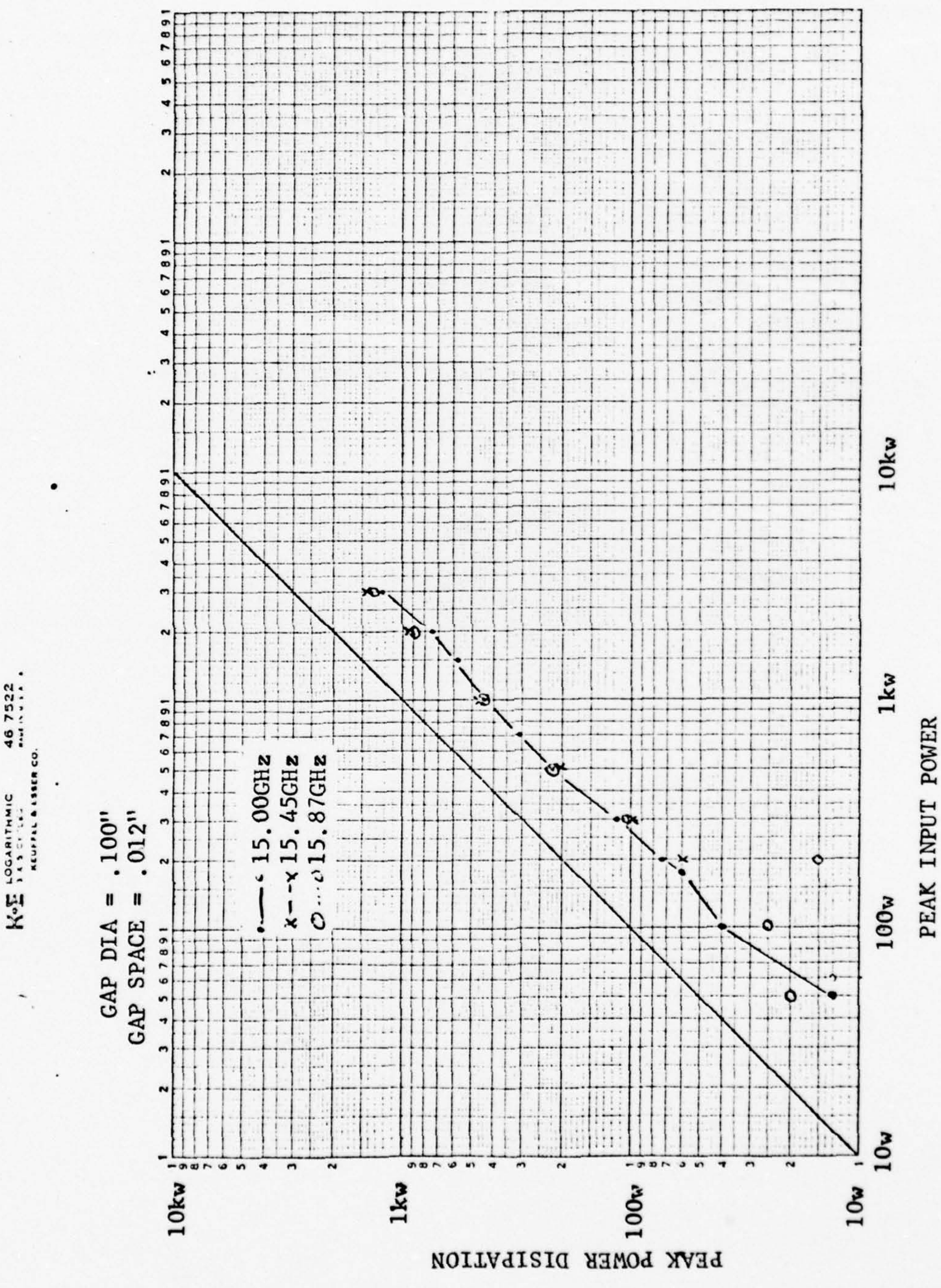


FIGURE 6C. DISSIPATION CHARACTERISTICS OF SINGLE TESTER

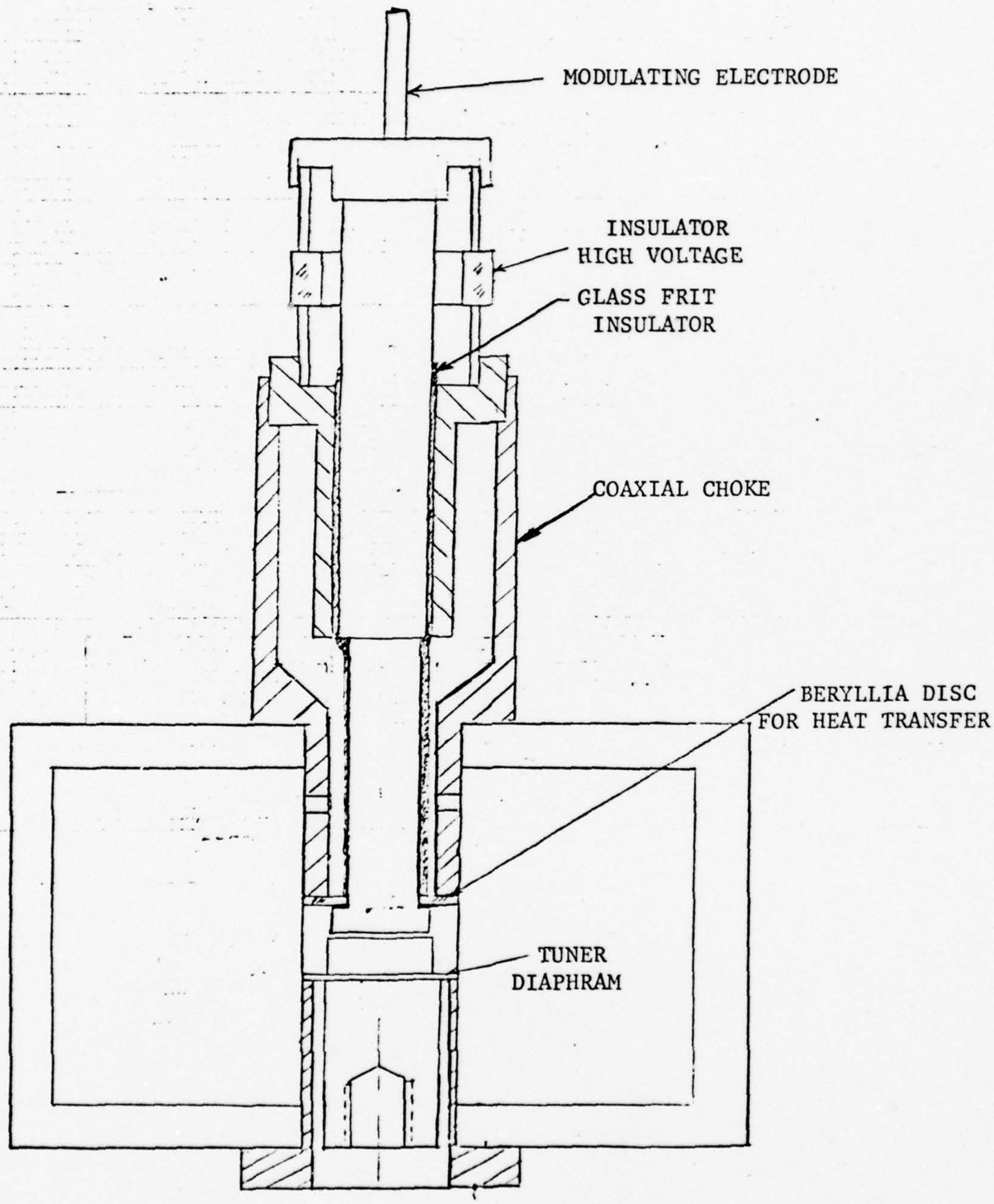
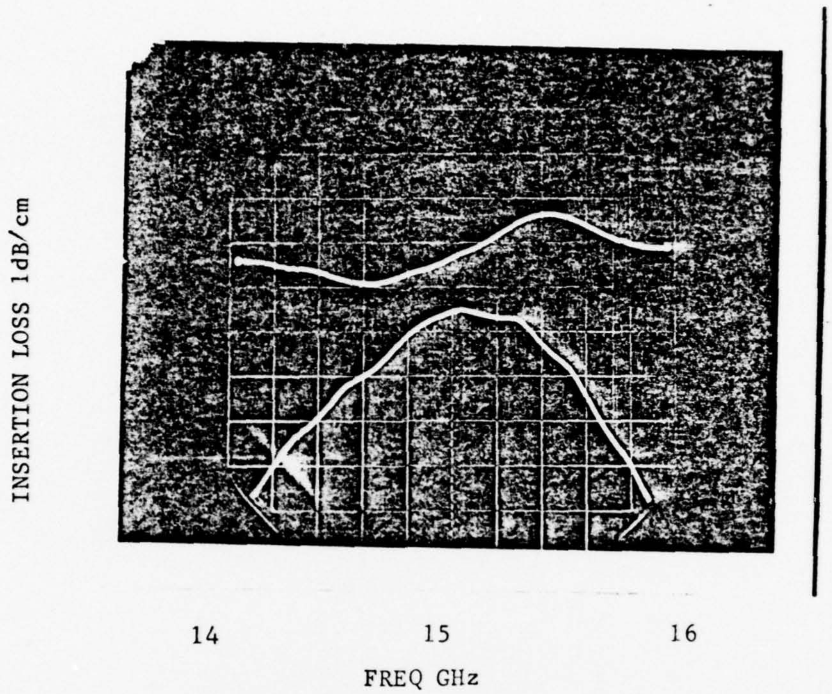


Figure 7. SKETCH OF BIASABLE BLUNT TR ELEMENT



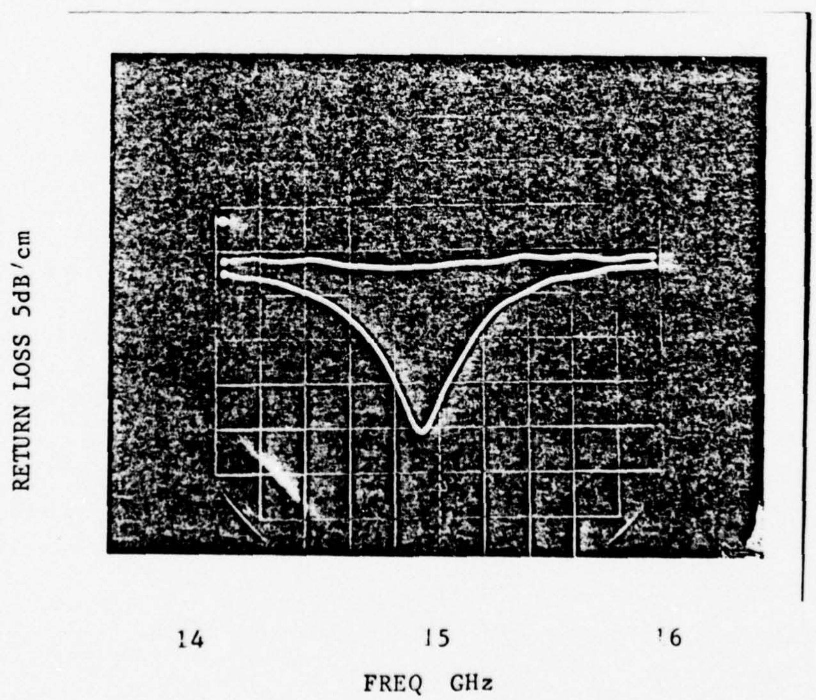


FIGURE 8. Low Level Characteristics of Biasable "Blunt" TR Element

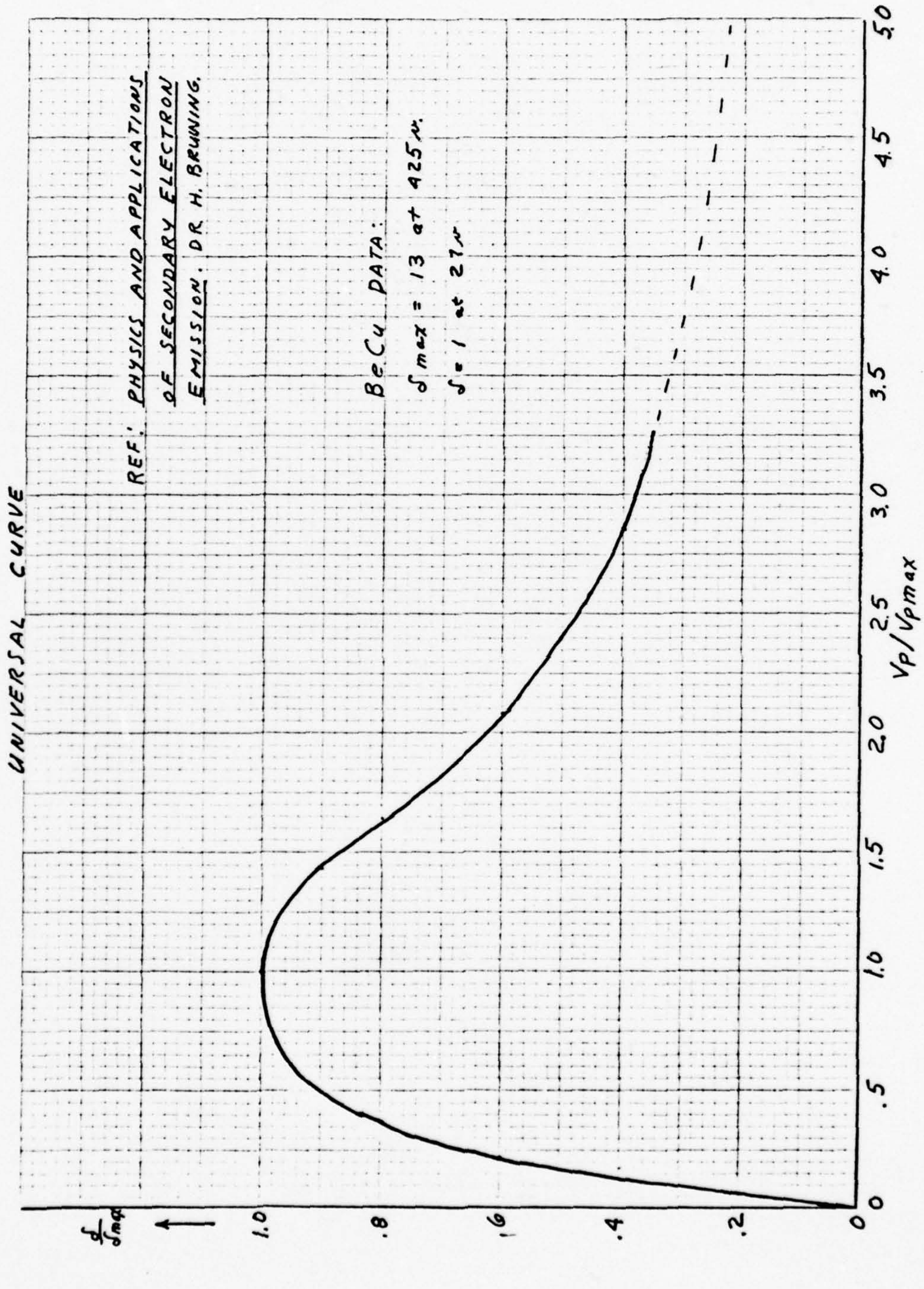


FIGURE 9. TYPICAL SECONDARY EMISSION CURVE

This surface support system was retained for use on the multipactor program, but in operation its effect on surface was not as pronounced as in the CFA's. In the multipactor discharge the ion bombardment is not a major factor and could explain some differences in replenishment of the surface between a CFA and a multipactor device. In the past, considerable effort has been devoted to processing of active tube cathodes and there is every reason to believe that such efforts will be needed to obtain satisfactory life and minimize starting jitter with multipactor devices.

In the devices tested there was frequently a finite time required for the multipactor to occur. This is observed as a spike of energy passing through the device. To minimize starting delay a copious supply of free electrons is desired at all times. Toward this end Varian applied radiotive material (PM147) in the vicinity of the interaction area; however, starting difficulties were apparent. Radioactive tritium (H_3) in gasseous form was also tried without success.

2. Space Charge Loading

An interesting effect of space charge is its lowering of capacitance. In a narrow band resonant circuit this change of capacitance can provide a means of making a single pole-double throw switch. In a broad band circuit the capacity change merely perturbs the match empedance.

Using the method of Forrer and Milazzo (Ref. 1) and a test vehicle with a multipactor gap length of d = .0122 inches and an operating frequency of 15 GHz, $d/\lambda = .0155$, the geometrical voltage is $V^* = 4846$ volts. For the one half cycle mode, θos if between 32.5 degrees and 40 degrees; thus using Figure 6 of the reference $Vi/V^* = 0.1$ or $Vi = 485$ volts. From the experimental data the power disipated, Pd, was 1300 watts with 3 kw of incident RF power.

$$Vi \cdot Irms = Pd.$$
$$Irms = 1300/485 = 2.68 \text{ amps}$$

For a multipacting device the average discharge current,

$$Ic = Irms\ \left(\frac{2\sqrt{2}}{\pi}\right) = 2.413 \text{ amps}$$

Using this current in equation 29 of the reference

$$Ic = \frac{4\pi}{\mu o}\sqrt{\frac{V}{\eta}}\ \frac{k^2}{2N-1}\ \gamma^2$$

Where $N = 1$

$$k = r_m/\lambda = .05/.7866 = 0.0636$$

$$\therefore \gamma^2 = .1143$$

This indicates (from Figure 8 of the reference) a net secondary emission ratio of only 2.8 for the beryllium copper secondary emitter.

Knowing the current within the device, it is now possible to calculate the capacitive tuning of the resonant gap.

$$fo = \frac{1}{2\pi\sqrt{LC}}$$

$$fsc = \frac{1}{2\pi\sqrt{LKC}} = fo/\sqrt{K}$$

where fo is the low level resonant frequency and fsc is the resonant frequency with space charge.

The relative dielectric constant with space charge is K, where

$$K = 1 - \frac{Ne^2}{m\varepsilon o\omega^2} \qquad \text{(Ref. 2)}$$

N = electron density (electron/meter^3)

e = electron charge (1.602×10^{-19} coulombs)

m = electron mass (9.1066×10^{-31} Kg.)

εo = permittivity of free space (8.854×10^{-12} Farad/meter)

ω = resonant frequency (radians/sec)

The electron density can be found from the relationship

$$N = \frac{Jo}{\nu_i e}$$

Where Jo is the current density, amps/m^3

$\eta = e/m = 1.76 \times 10^{11}$ coulombs/Kg.

$\nu_i = \sqrt{2\eta Vi}$

Vi = the striking voltage.

Using the data of single resonantor multipactor described

$$Ag = (2)\,\frac{\pi D^2}{4} = 0.0011 \text{ m}^2$$

$$N = 1.5 \times 10^{17} \text{ electrons/m}^3$$

$$K = 0.946$$

$$fsc = \frac{15 \text{ GHz}}{.946} = 15.42 \text{ GHz}$$

This compares quite well with the experimental conclusion that the shift was from 15 GHz to between 15.45 and 15.58 GHz.

Again the importance of this frequency shift becomes apparent when narrow band resonant circuits are used. The space charge loading can tune the resonator out of the band of interest such that incident power is primarily reflected.

With proper microwave circuitry such as a 3 port circulator, a single pole double throw switch can be made.

C. Dynamic Range

Dynamic range for this switch application is defined as the ratio of maximum transmitted output to minimum output. (For a none switchable limiter, it is defined as the ratio of maximum input power to leakage power).

Basically, a multipactor switch is first a limiter which absorbs or reflects incident power via the multipactor phenomena. To make a switch, a bias voltage or magnetic field is introduced which inhibits the resonant space charge flow. In this biased state, the entire RF signal is transmitted with low resistive losses.

The factors affecting dynamic range are varied, but primarily are the following:

1. Secondary Emission Characteristics
2. Voltage Breakdown Limitation
3. Isolation of Spurious Paths
4. Intrapulse or Interpulse Switching
5. Combination Switch and Limiter

1. Secondary Emission Factors

From various measurements the normal range of secondary emission greater than unity is from approximately 75 volts to approximately 2500 volts. Beryllium oxide and silver magnesium were found to have the lowest unity cross over points of approximately 25 and 35 volts respectively with the maximum secondary yield generally accurred with striking voltage of approximately 250 to 450 volts. Figure 10 is representative of the striking voltage vs. peak input power for circuits with various impedance values. As an example, assume that a circuit with 250 ohm impedance can be built for any desired gap spacing. The maximum input power to yield a secondary ratio greater than unity would be read at the intersection of the 2500 volt "Upper Secondary Emission Boundary" and 250 ohm circuit line, or approximately 30 kw. The minimum input power (the threashold power, or the leakage power) would be found by the intersection of the "Lower Secondary Emission Boundary" and the 250 ohm circuit line, or approximately 3 watts. The properly designed circuit with variable spacing optimized for the localized power would therefore have 30 db of dynamic range.

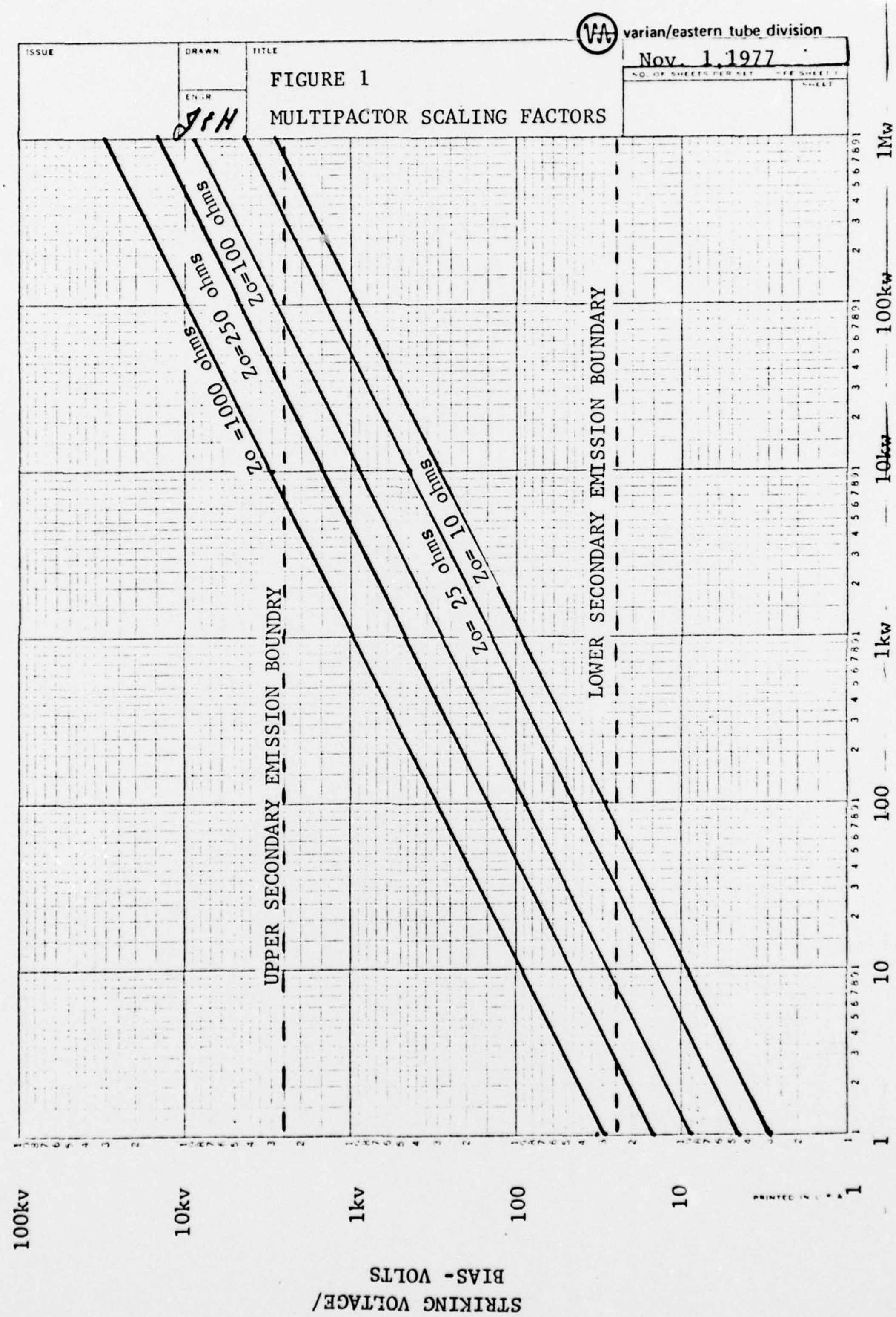


FIGURE 10 SCALING FACTORS FOR A MULTIPACTOR DEVICE(INDEPENDENT OF FREQUENCY)

If the circuit had programmed impedance such that the input sections were low impedance and the output sections were high impedance greater dynamic range "potential" exists. For example, a 25 ohm input and a 1000 ohm output would have P in max = 250 kw and a P out min of approximately one (1) watt yielding a "potential dynamic range" of 55.4 db. The bandwidth would be determined by the high impedance output stage.

2. Voltage Breakdown Limitations

The term "potential" dynamic range is used in the previous section because of other restrictions. For example, the output section will be tuned for the lowest threashold level consistant with secondary emission yield, impedance, and spacing. This inherently means that the gap spacing is small and the impedance is the highest obtainable, both of which tend to increase the voltage gradient near the output. However, the full incident power must pass through a switch, therefore the RF voltage gradient due to the peak incident power must be consistant with normal gradients. For example, at 15 GHz a 1000 ohm circuit with 5 watts multipactor level required a gap of only .0031 inches. At the 5 watt level the RF voltage gradient is only 33 volts/mil. If a maximum gradient of 1000 volts/mil is tolerated, the maximum RF level which can be transmitted through that localized gap is only about 1000 watts. Therefore, the dynamic range of the multipactor as a switch would be limited to only 23 db regardless of what was done at the input sections.

In addition to RF gradients, the dc voltage gradient must be added if the output section is switched.

No such limitation exists in a limiter because it is never desireable to pass the full peak input power with minimum loss.

3. Isolation Through Spurious Paths

In the circuit depicted in Figure 11A, there are two electrical paths shown. The first and fundamental path is through the desired multipactor region. The second is around the element described as the modulating electrode.

In the early stages of the program, much effort was devoted to minimizing stray leakage through this 2nd path. In any of the distrubited circuits indicated in section II the problem is real and must be solved. Based on circuit work the best estimate of dynamic range limitation due to this one factor is about 30 db.

In the resonant circuit developed later on in this program, similar paths exist as shown in Figure 11B. However, better choke sections are realizable and therefore the problem is believed to be under better control.

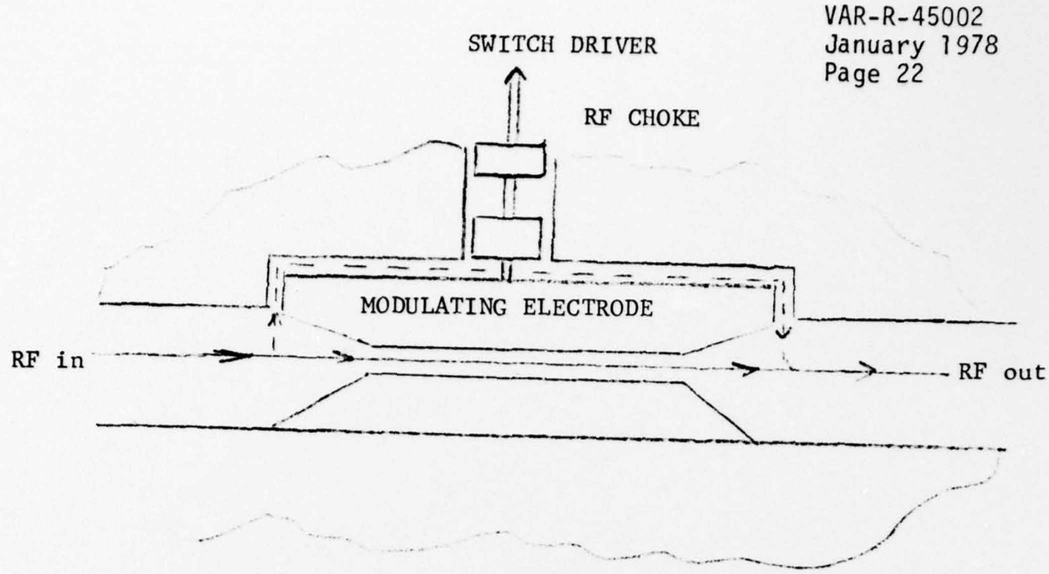


FIGURE SPURIOUS PATHS WITH DISTRIBUTED TRANSMISSION LINE

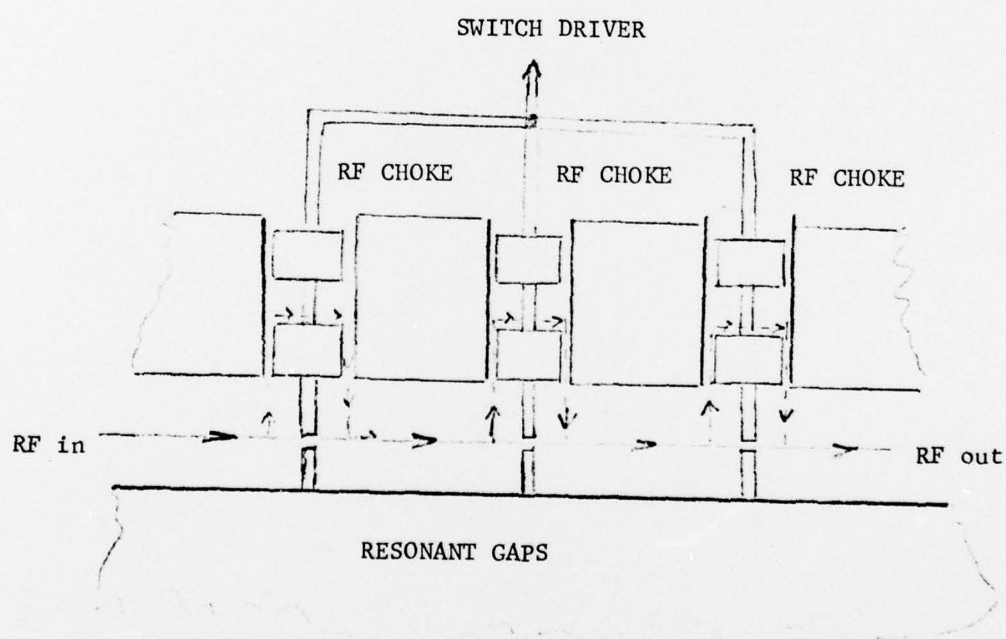


FIGURE 11. SPURIOUS PATHS WITH $\lambda/4$ COUPLED RESONANT GAPS

4. Intrapulse vs Interpulse Switching

When space charge effects are considered as in section B-2, it becomes possible to design for either a reflective or absorbtive switch.

a. Intrapulse Switching, Narrow or Broad Band

At the normal operating peak power levels, the multiplicator process can be initiated during the the main portion of the RF pulse. This phonemena can be interrupted by the application of a bias voltage which prevents electrons from striking one of the surfaces. With the removal of the bias, the power levels are within the range where the multipactor process can be restarted. If the circuit is narrow band the space charge can detune the natural resonance frequency such that some or most of the incident RF voltage is reflected(as was the case described in section B-2,)but the remaining RF voltage across the multipactor gap must be adequate to sustain the space charge and keep the cavity detuned. Such operation describes either a broad band or narrow band circuit capable of intrapulse switching.

b. Interpulse Switching

If the peak power is increased, and the bias voltage inhibiting multipactor is applied before the start of the RF pulse, the full peak RF will be applied across the multipactor gap. Beyond a certain peak RF voltage it will not be possible to start the multipactor mechanism with the removal of bias because of the accellerating RF voltage across the gap is too high and the resonance phenomena cannot exist. The onset of this non-multipactoring would seem to be a natural upper level for a multipactor switch; however, it is only the upper level of the intrapulse switching.

If the inhibiting bias is not applied at the beginning of the RF pulse, the proper RF voltage for multipacting will be present sometime during the rise of RF pulse. Few modulators can build up RF faster than the multipactor build up. If a broadband circuit is used the space charge will not sufficiently detune the circuit and essentially the incident RF voltage will continue to build up during the rise time and pass through the permissible multipactor resonance and extinguish. Such a device is not switchable any longer and therefore, in general, it may be concluded that a broadband circuit has essentially the same switching capability for either interpulse or intrapulse applications.

If a narrowband circuit is used, the space charge will build up and detune the circuit, thereby reflecting much of the incident RF voltage. With this type of circuit much higher RF levels can be applied than with a broadband circuit.

As an extra mode capability, this interpulse switch can be externally biased to interrupt the multipactor mode and switch to a transmission mode within the RF pulse. The converse, however, cannot be accomplished.

5. Combination Switch and Limiter

The circuit of the previous sections inferred that all elements involved in the multipactor process were biased to inhibit multipactor and also that there is an upper level of power beyond which the multipactor process is not sustainable.

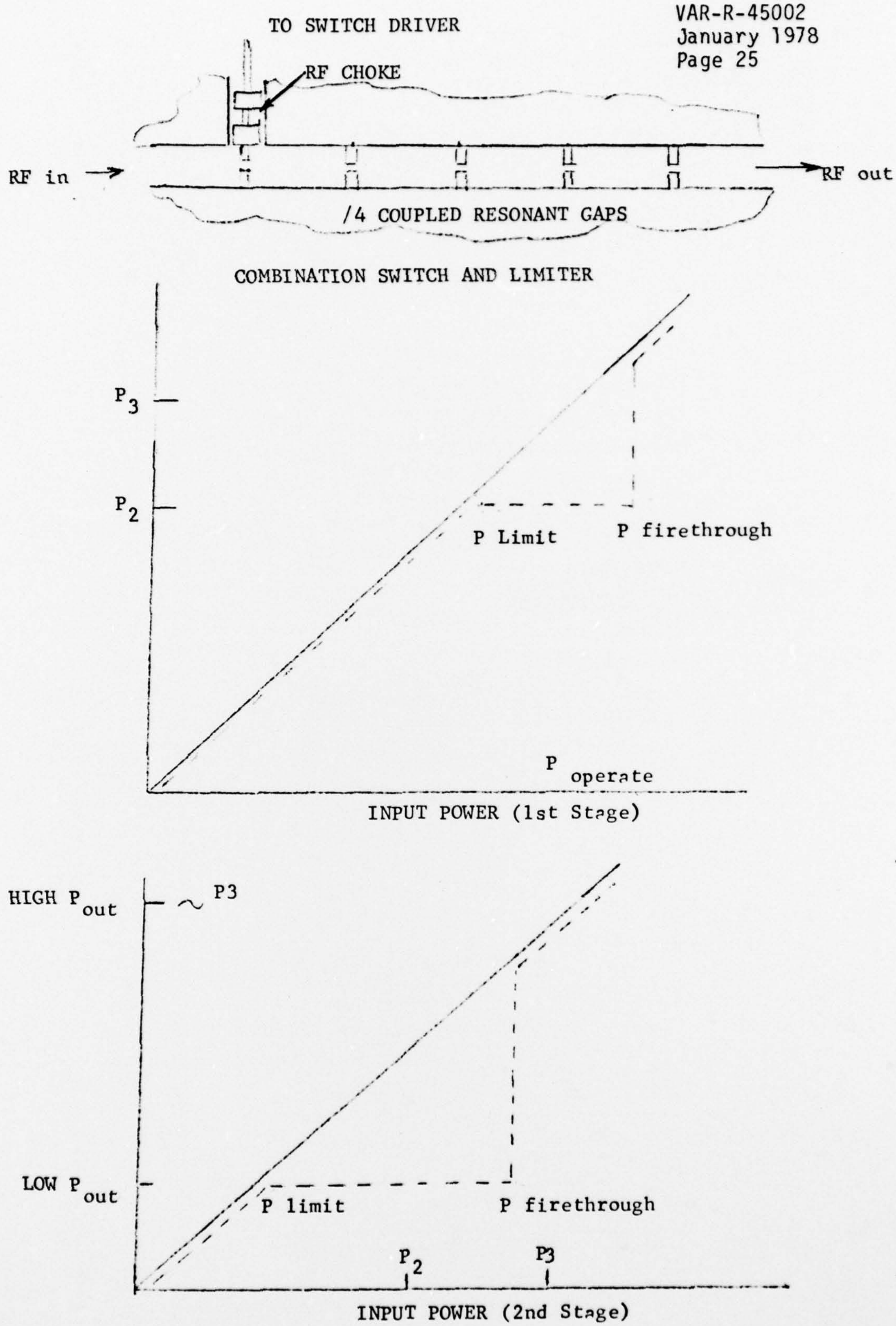
Consider now a device as shown in Figure 12 which consists of two distinct sections normally in a single vacuum envelope, but not necessarily so. The output section is a simple limiter with no switchable elements. Therefore, it has no spurious modes of transmission as described in Section D3. Because no dc potential need be applied, only RF breakdown must be considered. This factor could be used to design for either lower thresholds, higher average power transmission, or greater bandwidth.

An essential factor of this design is that the minimum switched RF level must be above the multipactor level of this output section.

The input section becomes the only switchable portion. Since the total circuit need not be switched, the load capacitance is reduced thereby minimizing the formidable external drive requirement.

The operation of this combination device is described as follows aided by Figure 12. As RF incident power is raised the output stage reaches its threashold and continues to limit until it reaches the fire through level. Biasing the input section has no effect on this performance below the fire through level of the output.

At power level above the fire through level of the output section, the input section becomes operational such that its localized multipacting is controlled by the external modulation. When the input section is biased no multipactoring occurs in the input and its output exceeds the fire through level of the output stage; the incident RF level passes through the entire device with only the passive insertion loss. When the bias is removed the input switchable section multipactors, reducing the signal to a level where the output sections multipactors, and limits to its threashold level. Switching the bias of only the input section therefore controls the output over a larger dynamic range than either section.



P_2 = Output Power 1st Stage When Multipactoring

P_3 = Output Power 1st Stage With Bias Inhibiting Multipactor

FIGURE 12. OPERATING POWER LEVELS OF COMBINATION SWITCH LIMITER

D. Driver Requirements

Most of the effort on the program concentrated on the multipactor device itself. However, there were certain restrictions which were felt to be essential for the device.

1. Since the maximum striking voltage for unity emission is approximately 2500 volts, this was considered the upper limit on the inhibiting voltage.

2. Since fast switching speeds were required the capacities switched was limited to 50 to 100 pf total.

In discussing fast drive circuits with Werner Brunhart of Eimac, the circuit shown in Figure 13 was said to be suitable for a multipactor device presenting approximately a 75 pf load at up to 1000 volts. By varying the length or RG 58/U, the output pulse width is adjustable.

To get a better picture of the switching problem the simple charging equation

$$Vi = \frac{1}{c} \int idt \sim \frac{\hat{i}\Delta t}{c}$$

yields the approximate current required from the driver. From this the peak power delivered by the driver can be approximately as $Vi \cdot i$ and the peak energy delivered per pulse can be approximated by

$$Ws(\mu \text{ joules}) = Vi \cdot \hat{i}\Delta t \ (\mu\text{sec})$$

Table I below indicates the relative value for a 50 pf load driven to Vi in 1 nanosec.

TABLE I

Vi Volts	$\hat{i}$ Amps.	Pp Driver Kw	Ws Driver μ joules
100	5	.5	.5
500	25	12.5	12.5
1000	50	50	50
1500	75	112.5	112.5
2000	100	200	200
2500	125	312.5	312.5

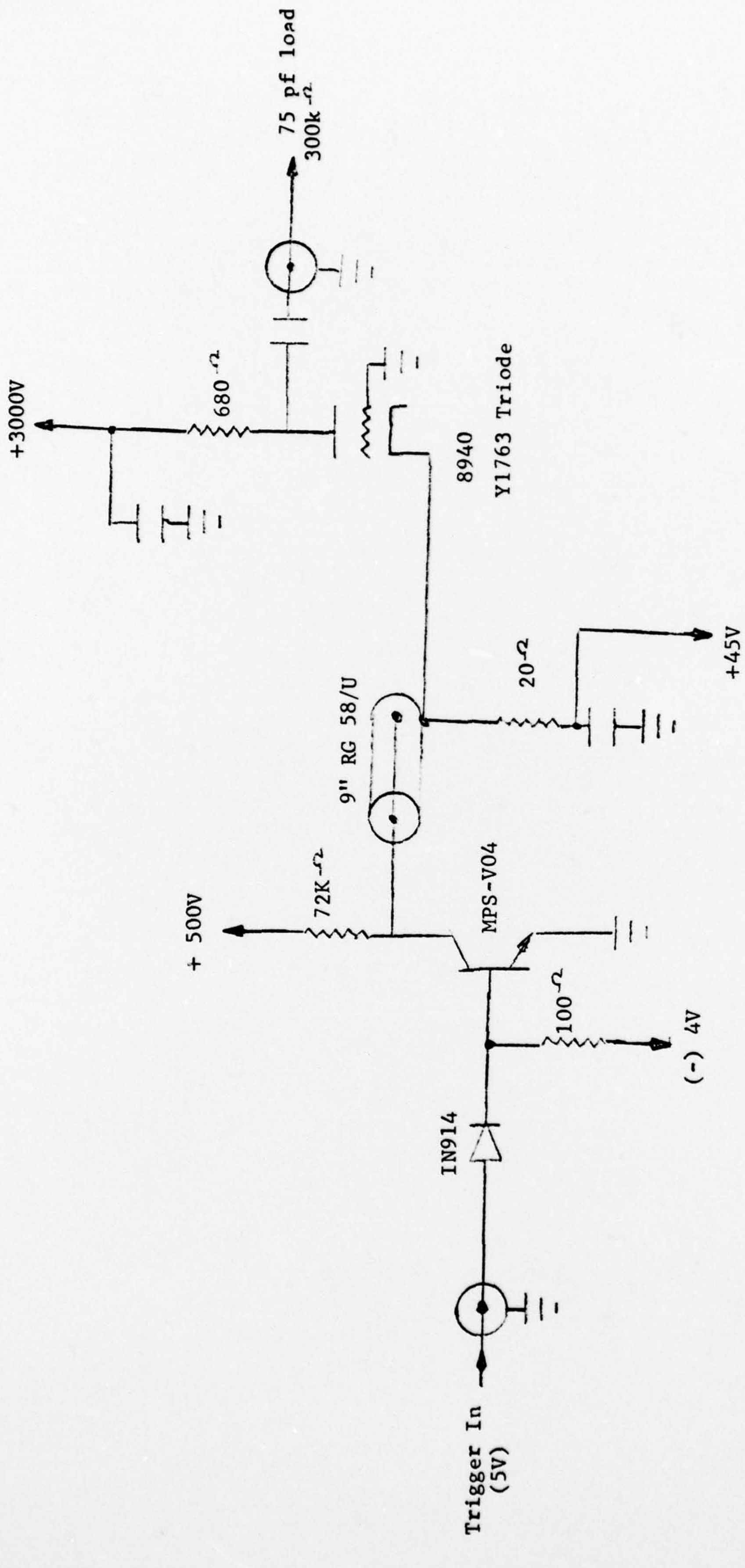


FIGURE 13. DRIVER CIRCUIT SUITABLE FOR 1000V MULTIPACTOR BIAS

III. SUMMARY OF DESIGNS

Based on the experience of this program,multipactor switches as tabulated in Table II,are believed to be realizable in substantial agreement with the goals of the work statement.

For 10% bandwidth designs, the "Blunt" TR resonant elements appear to be the most satisfactory design because of the high impedance, so necessary for low leakage. Gaps with spacings as small as .003 inches have been tested and appear practical from the stand point of reproducibility and low loss.

Similarly, the $\lambda/4$ coupled $\lambda/2$ resonator circuit has been found to have greater bandwidth than the above circuit with low loss at close spacings of approximately .003 inches. This second circuit appears to be the best choice for high duty and broad bandwidth because it can be effectively cooled especially at the lower frequencies.

For the J band designs, the basic limitation imposed was the practical gap spacing of .003 inches. At this spacing, the gap voltage for resonance is almost 100 volts; therefore the secondary yield should be quite adequate. At I band, both the spacing and the gap voltage indicate the limits of .003 inches. At lower frequencies the gap spacing would be increased in accordance with gap voltage to maintain a minimum striking energy of approximately 30 eV. The J band design is therefore mechanically limited to about 5 watts of leakage while the I band on lower frequency devices would be limited by secondary yield to about 1 watt of leakage. For this reason the J band device with 1 kw input should have less dynamic range than comparable lower frequency designs.

When the lower impedance broad band circuit is used, the higher input power levels are permissible, but again with the penalties of higher threshold leakage and higher capacity circuits. For the higher duty operation the peak input power must be reduced to limit heating.

Based on the measured power reflected with the 10% bandwidth circuit, the thermal calculations were based on only 50% of the incident power being absorbed within such devices. That 50% power loss in turn was split between the two balanced halves of the circuit, and the thermal impedance of the switching element was used as that determining the maximum temperature rise. With a temperature rise of 275° permitted to the heat sink, the maximum expected temperature would be limited to about 400°C which is a safe design criterion.

For the broad band circuit it was assumed that the space charge detuning would be minimal and the full incident power was dissipated in the first section in determining its temperature rise.

The capacitances given in Table II of 30 and 40 Pf corresponds to the estimated capacitance per resonant section.

If sufficient driver energy were available several or all of the elements could be biased without really affecting the tabulation.

TABLE II SUMMARY OF DESIGNS

Circuity Types (1) $\lambda/4$ Coupled Blunt TR (2) $\lambda/4$ Coupled $\lambda/2$ Resonator

PARAMETER	J BAND fo = 15 GHz			I BAND fo = 10.36 GHz		
BANDWIDTH	10%	40%	40%	10%	40%	40%
CIRCUIT TYPE	(1)	(2)	(2)	(1)	(2)	(2)
DUTY CYCLE	20%	2.5%	50%	40%	3.5%	50%
CIRCUIT IMP. (ohms)	1000	100	100	1000	100	100
PINPUT. (kw)	1	50	1.25	1	50	1.8
P OUT (w)(multipactor)	4.5	45	45	1	10	10
INSERTION LOSS (db)	1.5	1.5	1.5	1	1	1
DYNAMIC RANGE (db)	23.5	30	14.5	30	37	22.5
Vz INPUT (VOLTS)	1414	3.62	500	1414	3162	600
Vz OUTPUT (VOLTS)	93.6	93.6	93.6	45	45	45
V‡ OUTPUT (eV)	60	60	60	29	29	29
d INPUT (inches)	.0116	.0174	.0069	.0169	.0254	.011
d OUTPUT (inches)	.003	.003	.003	.003	.003	.003
E max OUTPUT (VOLTS/MIL)	470	1054	166	470	1054	200
BIAS (VOLT)	900	2000	320	900	2000	380
CAPACITANCE (pf)	30	40	40	30	40	40
THERMAL IMP. ($^{o}C/w$)	5.5	.45	.45	2.7	.31	.31
ΔT max. (^{o}C)	275	275	275	275	275	275

IV. CONCLUSIONS

Multipactor switches appear feasible within the general guidelines of the study. There is no easy way to rapidly modulate these devices without supplying substantial amounts of power. Voltages, however, are quite reasonable with 2.5 kv being about the maximum desireable. Similarly, the driven capacitance does not appear to rapidly increase with decreasing frequency.

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